arXiv:hep-ph/9310277v1 13 Oct 1993

Discovering Supersymmetry
with Electron and Photon Beams[1]

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Abstract

Linear collider designs are optimized for e^+e^- collisions. However, from the physics point of view, linear colliders may also be advantageously operated in an e^-e^-, $e^-\gamma$ or $\gamma\gamma$ mode. These options, which have not been available up to now, will provide unique tests of the standard model and of physics beyond it. As an example, we review the prospects for discovering and studying supersymmetry at linear colliders in e^-e^-, $e^-\gamma$ and $\gamma\gamma$ collisions. In particular, we argue that e^-e^- scattering is much better suited than e^+e^- annihilation for discovering selectrons or charginos.

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[1] Contribution to the Proceedings of the Workshop on Physics with e^+e^- Linear Colliders, Annecy, February 15-16, 1993.

1   Introduction

Linear colliders would be most versatile tools in experimental high energy physics. Not only can they provide e^+e^- collisions at high energies and luminosities, but also very energetic beams of real photons. One could thus exploit $\gamma\gamma$, $e^-\gamma$ and even e^-e^- collisions for physics studies. In addition, it appears feasible to produce beams with a high degree of polarization. Summing up all combinations of polarizations and beams, one finds that at least 14 different experiments can be performed at the same linear collider.

These exciting prospects have prompted a growing number of theoretical studies devoted to the investigation of the physics potential of such new accelerator experiments. Just to cite a few of the possibilities: e^-e^- reactions are ideal for observing lepton number violating processes [1, 2]; $e^-\gamma$ scattering would reveal excited electrons as sharp resonances [3]; $\gamma\gamma$ collisions are powerful probes of the CP quantum numbers of Higgs bosons [4] and of anomalous gauge couplings [5].

We summarize here the latest results known to us in the field of supersymmetric phenomenology at linear colliders with polarized and unpolarized electron and photon colliding beams. For this we first outline how high energy photon beams can be obtained [6]. We then discuss the supersymmetry parameters which are relevant to selectron and chargino production and decay. In section 4, we consider the production of charginos and selectrons in polarized and unpolarized e^-e^- collisions [7, 8]. We emphasize that this channel is almost free from standard model backgrounds, in contrast to e^+e^- reactions. Section 5 is devoted to the study of $e^-\gamma$ [9, 10, 11, 12] collisions, while section 6 deals with $\gamma\gamma$ [13, 14] collisions. Finally, we summarize the main conclusions of this study and point out questions which require further investigation.

2   Photon Beams

High energy photons can be obtained in three ways at linear colliders:

1. Bremsstrahlung off the initial electrons or positrons. The spectrum is given in the Weizsäcker-Williams approximation [15] by the familiar equivalent photon function

$$P(y) \;\; = \;\; \frac{\alpha}{2\pi}\frac{1+(1-y)^2}{y}\ln\frac{s_{ee}}{m_e^2} \;\; , \tag{1}$$

   where α is the fine structure constant, y is the fraction E_γ/E_e of the photon and $e^\pm$ beam energies, m_e is the electron mass, and $\sqrt{s_{ee}} = 2E_e$ is the nominal collider energy in the e^+e^- mode.

2. Beamstrahlung which results from the interaction of the two beams. In general, the shape and intensity of the photon distribution depend very much on the beam parameters [16].

3. Compton back-scattering of intense laser pulses on the bunches of one or both beams. The energy distribution is given by [6]

$$P(y) = \frac{1}{N}\left(1 - y + \frac{1}{1-y} - \frac{4y}{x(1-y)} + \frac{4y^2}{x^2(1-y)^2}\right) , \qquad (2)$$

where

$$0 \leq y \leq \frac{x}{x+1} \qquad \text{and} \qquad x = \frac{4E_e E_{\text{laser}}}{m_e^2} . \qquad (3)$$

The factor

$$N = \frac{1}{2} + \frac{8}{x} - \frac{1}{2(1+x)^2} + \left(1 - \frac{4}{x} - \frac{8}{x^2}\right)\ln(1+x) \qquad (4)$$

normalizes $\int dy\, P(y)$ to 1.

In contrast to the first two mechanisms which take place more or less naturally, it is not a trivial task to implement laser Compton back-scattering. On the other hand, this option yields a much harder photon spectrum and is thus much better suited for the photoproduction of heavy particles. For this reason we concentrate here on this third option where the photons obey the distribution (2).

In what follows, we assume a 100% conversion efficiency and neglect the angular dispersion of the back-scattered photons. When x reaches the value $2(\sqrt{2}+1) \approx 4.83$, the back-scattered and laser photons have enough relative energy to produce e^+e^- pairs. As a consequence, the conversion efficiency drops considerably for larger values of x. We therefore assume the laser energy to be tuned in such a way as to obtain $x = 2(\sqrt{2}+1)$. The corresponding energy spectrum (2) is displayed in Fig. 1. It sharply contrasts with the energy spectrum of Bremsstrahlung photons, which is much softer and, hence, less useful for heavy particle searches.

If the electron and/or laser beams are polarized the spectrum depicted in Fig. 1 can be substantially modified and become either softer or harder. Nevertheless, the hardest photons obtained in this way will never exceed an energy of $\frac{x}{x+1}E_e = 2(\sqrt{2}-1)E_e \approx .83E_e$. This means that in $e^-\gamma$ and $\gamma\gamma$ collisions the effective centre of mass energy is reduced by about 10 % and 20 %, respectively, in comparison to the e^+e^- and e^-e^- collision energies.

Moreover, the cross sections of $e^-\gamma$ and $\gamma\gamma$ reactions involving such a back-scattered photon beam have to be folded with the energy distribution (2). The laboratory frame is thus not the centre of mass frame and the $e^-\gamma$ and $\gamma\gamma$ centre of mass energies $\sqrt{s_{e\gamma}}$ and $\sqrt{s_{\gamma\gamma}}$, respectively, are given by

$$s_{e\gamma} = y s_{ee} \qquad \text{and} \qquad s_{\gamma\gamma} = y_1 y_2 s_{ee} , \qquad (5)$$

where the different y's denote the photon energy fractions. Finally, the convoluted cross sections are obtained from

$$\sigma(s_{ee}) = \int dy\, P(y)\sigma(s_{e\gamma}) \qquad \text{and} \qquad \sigma(s_{ee}) = \int dy_1 \int dy_2\, P(y_1)P(y_2)\sigma(s_{\gamma\gamma}) . \qquad (6)$$

3 Supersymmetry Parameters

In spite of its economy of principles, a supersymmetric extension of the standard model [17] involves an opulent number of additional free parameters. Although the strengths of the interactions must be precisely the same as those of the standard model, at this stage the masses and eventual mixings of the supersymmetric partners of the conventional particles cannot be predicted from first principles. The most relevant parameters here are the mass parameters M_1, M_2, μ associated with the $U(1)$ and $SU(2)_L$ gauginos and the higgsinos respectively, the ratio $\tan\beta = v_2/v_1$ of the Higgs vacuum expectation values and the slepton masses. We work in the context of the minimal supersymmetric standard model and make the following assumptions:

1. R-parity is a conserved quantum number.

2. The lightest neutralino $\tilde{\chi}_1^0$ is the lightest supersymmetric particle.

3. All sleptons have the same mass and are much lighter than the strongly interacting squarks and gluinos: $m_{\tilde{\ell}_L} = m_{\tilde{\ell}_R} = m_{\tilde{\nu}_\ell} \ll m_{\tilde{q}}, m_{\tilde{g}}$.

4. The mass parameters M_1, M_2, μ are real.

5. At the GUT scale $M_1 = M_2$, so that after renormalization to accelerator energies $M_1 = 5/3\, M_2 \tan^2\theta_w$, where θ_w is the weak mixing angle.

The first two assumptions are essential, because they dictate the whole supersymmetric phenomenology: all sparticles decay directly or via a cascade into the lightest supersymmetric particle which is stable and escapes detection. The last three assumptions are made for simplicity and can be relaxed without modifying qualitatively the conclusions. As a consequence of these assumptions there are thus only four parameters left

$$\boxed{\tan\beta \quad M_2 \quad \mu \quad m_{\tilde{\ell}}}$$

which are relevant for the present studies. Of these four parameters, $\tan\beta$ is the least influential, at least when it is larger than 2. In contrast, the results can be very sensitive to variations of the other three parameters.

In the following we only consider the production of the lightest chargino and sleptons (typically the selectron), since according to our third assumption strongly interacting sparticles are too heavy to be produced competitively. Since the chargino and the selectron decay only through electroweak interactions, their lifetimes are typically long in comparison to their mass scale. It is therefore safe to use the narrow width approximation.

The simplest decay mode of the selectron is into an electron and the lightest neutralino:

$$\tilde{e}^- \rightarrow e^- \tilde{\chi}_1^0 \ . \tag{7}$$

Since we assume the neutralino to be the lightest supersymmetric particle, only the electron is visible. If kinematically allowed, other decays can take place like

$$\tilde{e}^- \quad \rightarrow \quad e^- \tilde{\chi}_2^0 \; , \tag{8}$$

$$\rightarrow \quad \nu_e \tilde{\chi}_1^- \; , \tag{9}$$

and similar decays into the heavier neutralino and chargino states. The supersymmetric particles produced in this way will decay into lighter (s)particles, which themselves might undergo further decays until only conventional particles and a number of the lightest neutralino remain. The end-product of such cascade decays can sometimes again be an electron accompanied by invisible particles only. Whenever such cascade decays are important (*i.e.* when no high transverse momentum cuts need to be imposed on the emerging electrons) we compute the branching ratio for the decay $\tilde{e}^- \rightarrow e^- +$ invisible, with the two-body decay algorithm described in Ref. [18]. Typically, the left-selectron (*i.e.* the partner of the left-handed electron) has a lower branching ratio for the decay (7) than the right-selectron, because the latter cannot decay into charginos.

The decays of charginos are more complicated. Concentrating on the lightest chargino, if kinematically allowed to do so, it will decay into leptons and sleptons or charged bosons and neutralinos:

$$\tilde{\chi}_1^- \quad \rightarrow \quad \ell^- \tilde{\nu}_\ell \; , \tag{10}$$

$$\rightarrow \quad \tilde{\ell}^- \nu_\ell \; , \tag{11}$$

$$\rightarrow \quad W^- \tilde{\chi}_i^0 \; , \tag{12}$$

$$\rightarrow \quad H^- \tilde{\chi}_i^0 \; . \tag{13}$$

For simplicity, we discard here the last possibility (13) by assuming the charged Higgs boson to be heavy. If the chargino is heavier than the sleptons, it will preferentially decay with approximately a 50% branching ratio in each of the channels (10) and (11) and with democratic probabilities for the different flavours [14]. In this case, the sleptons can only decay further into leptons and neutralinos. If the chargino is lighter than the sleptons but can still decay according to the reaction (12), one has to deal with a W^- signal. It can also happen that none of the two-body decays (10-13) is kinematically allowed. If this is the case and if the mass of the sleptons is much larger than the mass of the W, the decay through a virtual W dominates. The branching ratio of the leptonic decay $\tilde{\chi}_1^- \rightarrow \ell^- \bar{\nu}_\ell \tilde{\chi}_1^0$ is then approximately 42% [19].

In the next sections, where we consider selectron and chargino production, we focus on the decay signatures:

$$\boxed{\begin{array}{ccl} \tilde{e}^- & \rightarrow & e^- + \not{p}_\perp \\ \tilde{\chi}_1^- & \rightarrow & \mu^- + \not{p}_\perp \end{array}}$$

4 $e^- e^-$ Collisions

In $e^- e^-$ collisions chargino and selectron production are both accessible. The most striking signatures are, respectively, $e^- e^- \rightarrow \mu^- \mu^- + \not{p}_\perp$ and $e^- e^- \rightarrow e^- e^- + \not{p}_\perp$. We summarize

here the results [8] for each reaction.

4.1 Chargino Production

Chargino production takes place in e^-e^- collisions via the exchange of a sneutrino, as depicted in Fig. 2. The energy dependence of the cross section is also shown in Fig. 2 for a particular choice of supersymmetry parameters. The yield is sharply peaked just above threshold so that an appropriate energy scan can provide information about the mass of the chargino. We focus here on the following observable signal originating from the chargino decays (10–12)

$$\boxed{e^-e^- \to \tilde{\chi}_1^- \tilde{\chi}_1^- \to \mu^- \mu^- + \not{p}_\perp}$$

The cross section for obtaining this signal can be much lower than the total production cross section, because the branching ratio of the decay of a chargino into a muon and invisible particles is always lower than $1/3$. Still, the dominant standard model background due to the process

$$e^-e^- \to W^- \nu_e W^- \nu_e \quad , \tag{14}$$
$$\hookrightarrow \mu^- \bar{\nu}_\mu$$
$$\hookrightarrow \mu^- \bar{\nu}_\mu$$

should not exceed 1 fb for $\sqrt{s_{ee}} = 500$ GeV. This is very different in e^+e^- reactions, where it is difficult to disentangle a supersymmetric $\mu^+\mu^- + \not{p}_\perp$ signal from the large standard model background, mainly due to W pair production.

In Fig. 3 we have plotted the contours in the (μ, M_2) half-plane along which the observable cross section for the $\mu^-\mu^- + \not{p}_\perp$ signal from the decay modes (10-12) is 1, 10 and 100 fb. For this we assumed a mass of 300 GeV for the exchanged sneutrino. As long as $M_2 \lesssim 300$ GeV, the signal to background ratio should comfortably exceed one. To compute these cross sections we used a theorists' detector by imposing the following rapidity, energy and acoplanarity cuts on the observed leptons:

$$|\eta_e| < 3 \quad , \quad E_e > 5 \text{ GeV} \quad , \quad ||\phi(\ell_1^-) - \phi(\ell_2^-)| - 180°| > 2° \ , \tag{15}$$

where ϕ is the azimuthal angle of the decay leptons with respect to the beam axis.

4.2 Selectron Production

Selectron production takes place in e^-e^- collisions via the exchange of neutralinos, as depicted in Fig. 4. Note that all four neutralinos play an important role in this reaction [18]. The dependence on the supersymmetry parameters is thus rather complex because it enters at three different levels: (i) through the masses of the four different neutralinos; (ii) through their mixings among each other which affects their couplings to electrons and selectrons; (iii) through the mass and branching ratios of the selectron.

The energy dependence of the cross section is shown in Fig. 4 for the same choice of supersymmetry parameters as previously. Also here, the yield is sharply peaked just

above threshold so that an energy scan can provide precise information about the mass of the selectron. The prominent decay mode (7) leads to the following observable signal:

$$\boxed{e^- e^- \to \tilde{e}^- \tilde{e}^- \to e^- e^- + \not{p}_\perp}$$

The cross section for obtaining this signal is comparable with the total production cross section in a large part of the parameter space considered. Indeed, if the selectron is light it can only decay as in Eq. 7 so that the branching ratio of the decay of a selectron into an electron and invisible particles is one. In addition, for most choices of the relevant supersymmetry parameters the right-selectron will exclusively decay according to Eq. 7. The most important background from the standard model processes

$$e^- e^- \to e^- \nu_e W^- \qquad \text{and} \qquad e^- e^- \to e^- e^- Z^0 \quad (16)$$
$$\hookrightarrow e^- \bar{\nu}_e \qquad\qquad\qquad\qquad \hookrightarrow \nu\bar{\nu}$$

is not particularly high. After imposing the acceptance cuts (15) and including the relevant branching ratios, the cross sections are 150 fb for W^- and 40 fb for Z^0 Bremsstrahlung, at $\sqrt{s_{ee}} = 500$ GeV. The potential background from Møller scattering is eliminated by the acoplanarity cut. The supersymmetric signal, on the other hand, is not significantly reduced by these mild cuts (which basically simulate a typical detector acceptance).

Note that softer electrons emerging at the end of a longer cascade such as the ones initiated by the decays (8,9) will not be very much affected by the cuts (15) either. In contrast to the situation in $e^+ e^-$, $e^- \gamma$ and $\gamma\gamma$ collisions, where high transverse momentum cuts are necessary in order to enhance the signal to background ratio, $e^- e^-$ scattering is thus ideal for observing and studying supersymmetric cascades.

In Fig. 5 we have plotted the contours in the (μ, M_2) half-plane along which the observable cross section for the $e^- e^- + \not{p}_\perp$ signal from the production of 200 GeV selectrons is 1 and 0.1 pb. The dotted lines show what is obtained if one ignores those cascade decays (e.g. (8,9)) of the selectron which yield the same $e^- e^- + \not{p}_\perp$ final states as the direct decay (7).

4.3 Polarized Beams

Polarization can enhance the chargino signal together with the background by up to a factor four. This is a welcome but not dramatic effect.

For selectrons, on the other hand, the signal can be strongly enhanced or suppressed with polarized beams, depending on the values taken by the supersymmetry parameters. The main virtue of polarization, however, is that with right-handed electron beams the W^- Bremsstrahlung background (16) disappears. It is then worthwhile to also eliminate the background from Z^0 Bremsstrahlung, in order to select a really clean sample of supersymmetric events with no, or negligibly little, background from standard model processes. This can be done by rejecting all $e^- e^-$ events with a total deposited energy exceeding about half the centre of mass energy

$$E_{e_1} + E_{e_2} < \frac{s - m_Z^2}{2\sqrt{s}} \approx 242 \text{ GeV} . \quad (17)$$

6

If this cut is imposed, none of the Z^0 contributes and at worst 55% of the electron pairs which originate from selectron production are lost. The dominant irreducible background then originates from double W^- Bremsstrahlung (14). It should not amount to more than 1 fb. Note that with e^+e^- beams, the standard model backgrounds cannot be eliminated in such a simple way. We have plotted in Fig. 6 the same contours as in Fig. 5 for right-polarized beams.

Note that with such a polarization experiment, not only are the allowed values of the supersymmetry parameters further restricted, but also the mass of the neutralino can be kinematically determined from the endpoints $E_{\text{min,max}}$ of the electron energy distribution:

$$m_{\tilde{\chi}_1^0}^2 = \sqrt{s_{ee}} \frac{E_{\max} E_{\min}}{E_{\max} + E_{\min}} \left(\frac{\sqrt{s_{ee}}}{E_{\max} + E_{\min}} - 2 \right) . \tag{18}$$

Of course, there will always be some smearing due to initial state Bremsstrahlung and beamstrahlung. The incidence of these effects should be further investigated. We emphasize that this interesting possibility does not exist in e^+e^- collisions.

5 $e^-\gamma$ Collisions

We have seen in the previous section that if selectrons or charginos are light enough to be pair-produced in e^-e^- collisions this will yield an unmistakable signal. However, if the collider energy is below the pair-production threshold it is the $e^-\gamma$ operating mode which may save the day [12]. As depicted in Fig. 7, $e^-\gamma$ collisions can produce selectrons in association with the lightest neutralino and thus probe higher selectron masses than e^-e^- collisions.

The energy dependence of the cross section is also shown in Fig. 7 for the same choice of supersymmetry parameters as previously. If the selectron decays in the channel (7), the observed signal is quite striking:

$$\boxed{e^-\gamma \rightarrow \tilde{e}^- \tilde{\chi}_1^0 \rightarrow e^- + \not{p}_\perp}$$

Unfortunately, the standard model backgrounds from the reactions

$$e^-\gamma \rightarrow \nu_e W^- \qquad \text{and} \qquad e^-\gamma \rightarrow e^- Z^0 \atop \hookrightarrow \nu\bar{\nu} \, , \tag{19}$$
$$\hookrightarrow e^-\bar{\nu}_e$$

are substantial. At $\sqrt{s_{ee}} = 500$ GeV the corresponding cross sections amount to about 3 pb each. However, by imposing the transverse momentum and rapidity cuts

$$p_\perp(e^-) > 50 \ \text{GeV} \qquad \text{and} \qquad 0 < \eta(e^-) < 2 \, , \tag{20}$$

the combined background can be reduced to less than 0.3 pb. These cuts enhance the signal to background ratio by more than an order of magnitude.

For the sake of illustration, we now consider a selectron with $m_{\tilde{e}} = 250$ GeV, which cannot be pair-produced in 500 GeV $e^\pm e^-$ collisions. In Fig. 8 we show the contours in the

(μ, M_2) half-plane along which the signal exceeds the backgrounds statistical fluctuations by more than 3 standard deviations, i.e. $n_{SUSY} > 3\sqrt{n_{SM}}$. The shaded area shows the part of parameter space which will already have been investigated by a chargino search in $e^{\pm}e^-$ collisions. Clearly, a deeper exploration of the parameter space requires very high luminosities.

The situation can be further improved by using left-polarized electron beams to cut down the W^- background (19). If the photon beam is also polarized (by polarizing the electron and laser beams) one can similarly reduce the Z^0 background [11]. A thorough study of these suggestions has still to be performed.

6 $\gamma\gamma$ Collisions

Sleptons can be pair-produced by colliding photon beams, as depicted in Fig. 9. The energy dependence of the cross section is also illustrated in Fig. 9. The threshold behaviour is washed out here by the broad energy distribution (2) of the colliding photons. Therefore, this reaction cannot yield much information on the mass of the selectron. Moreover, since the maximum $\gamma\gamma$ energy is almost 20 % lower than the e^+e^- or e^-e^- energies, this option is not competitive with the other linear collider modes for discovering charginos or sleptons.

On the other hand, $\gamma\gamma$ collisions posses the great advantage that there is no model dependence at the production level. This is because photons couple solely to electric charges, which are fixed even for hypothetical particles. One can, therefore, investigate the decay properties of the selectron separately in a clean way. This may yield important information on the gaugino-higgsino sector. The signal we focus on here

$$\gamma\gamma \to \tilde{e}^-\tilde{e}^- \to e^+e^- + \not{p}_\perp$$

has been analysed in [14]. The same analysis can be applied to the μ signal and, with some restrictions, also to the τ signal. Besides sleptons also charginos can be pair-produced in $\gamma\gamma$ collisions and decay into the final states considered above. However, the cross section for an observable signal is much lower.

The only potentially dangerous standard model background to the $\gamma\gamma \to e^+e^- + \not{p}_\perp$ signal is W pair production

$$\gamma\gamma \to W^+W^- \atop \substack{\hookrightarrow e^-\bar{\nu}_e \\ \hookrightarrow e^+\nu_e}. \tag{21}$$

However, the signal to background ratio can be substantially enhanced by imposing the transverse momentum, rapidity and acoplanarity cuts:

$$p_\perp(e^+)p_\perp(e^-) > m_W^2 \quad , \quad |\eta(e^\pm)| < 1 \quad , \quad ||\phi(e^+) - \phi(e^-)| - 180^\circ| > 2^\circ . \tag{22}$$

The last cut is imposed to eliminate the largest but simplest background from e^+e^--pair production $\gamma\gamma \to e^+e^-(\gamma)$. The background can be even further reduced without affecting the signal if the masses of the selectron and $\tilde{\chi}_1^0$ are already known (for example, from the

pair-production threshold in e^-e^- collisions and Eq. (18)). In that case, one can reject all events in which the electron energies lie outside the boundaries

$$\frac{\sqrt{s_{\gamma\gamma}^{\max}}}{4}\left[1-\frac{m_{\tilde{\chi}_1^0}^2}{m_{\tilde{e}}^2}\right]\left[1\pm\sqrt{1-\frac{4m_{\tilde{e}}^2}{s_{\gamma\gamma}^{\max}}}\right] \ , \tag{23}$$

where $\sqrt{s_{\gamma\gamma}^{\max}} = 2(\sqrt{2}-1)\sqrt{s_{ee}} \approx .83\sqrt{s_{ee}}$ is the maximum attainable centre of mass energy in the photon-photon collision.

The explorable parameter space is outlined in Fig. 10, where contours along which the signal exceeds the backgrounds statistical fluctuations by more than 3 standard deviations ($n_{SUSY} > 3\sqrt{n_{SM}}$) are depicted.

7   Summary and Conclusions

We have studied the production and decay of selectrons and charginos in e^-e^-, $e^-\gamma$ and $\gamma\gamma$ collisions. Our results can be summarized as follows:

e^-e^- Collisions:

$\oplus$ Privileged mode for **discovery**, because of inherently low standard model backgrounds. The signals are more striking than in e^+e^- collisions.

$\oplus$ Cascade decays of the selectron can be observed and studied, because no high transverse momentum cuts are needed to enhance the signal to background ratio.

$\ominus$ Difficult to disentangle the effects of masses, mixings and branching ratios.

$e^-\gamma$ Collisions:

$\oplus$ If selectrons are too heavy to be pair-produced, this is the only potential **discovery** mode.

$\ominus$ High luminosities are required. Polarization of the electron and photon beams helps.

$\gamma\gamma$ Collisions:

$\oplus$ Ideal mode for **study** of gaugino/higgsino parameters which determine the decay properties of sleptons.

$\ominus$ Reach in mass restricted due to the reduced energies of the photon beams relative to the initial energy of the electron beams.

Comparing e^+e^- and e^-e^- collisions it should be noted that while the production cross sections are similar in the two reactions, the latter suffers much less from the standard

model backgrounds. Hence, e^-e^- collisions are expected to provide the cleanest sample of supersymmetric events.

To conclude, we emphasize that the possibility of experimenting with (polarized) e^-e^-, $e^-\gamma$ and $\gamma\gamma$ beams is a unique feature of linear colliders, whose usefulness is by no means restricted to the search and study of supersymmetric particles. On the contrary, these options have been shown to also provide powerful tests of the standard model [20], anomalous gauge couplings [5], gauge extensions of the standard model [1], Majorana neutrinos [2], and many other interesting speculations. With such unique possibilities in mind one would clearly favor accelerator and detector designs which are not fundamentally preventing these options.

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Figure 1: Energy spectra of photons from laser Compton back-scattering (2) and Bremsstrahlung (1) for a 250 GeV electron beam.

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Figure 3: Contours in the supersymmetry parameter space of constant cross sections for the chargino signal. The cuts (15) are included. The chargino mass varies with M_2 and μ.

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Figure 5: Contours in the supersymmetry parameter space of constant cross sections for the selectron signal. The cuts (15) are included. The regions labeled "unphysical" are excluded since there $m_{\tilde{e}} < m_{\tilde{\chi}_1^0}$. The contours which would be obtained if cascade decays are ignored are also shown with dotted lines.

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Figure 6: Same as Fig. 5, for right-handed electron beams and the additional energy cut (17).

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Figure 8: Contours in the supersymmetry parameter space indicating the required luminosities for distinguishing a selectron signal from the standard model background at a 3σ confidence level. The cuts (20) are included. Results are shown for 10, 20, 50 and 100 fb^{-1} of integrated luminosities. The shaded area is explorable in $e^{\pm}e^{-}$ collisions. The dotted line indicates the kinematic boundary in $e^{-}\gamma$ scattering. The photon beam is assumed to have the energy spectrum (2).

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Figure 10: Contours in the supersymmetry parameter space indicating the luminosities required for distinguishing a selectron signal from the standard model background at a 3σ confidence level. The cuts (22,23) are included. For the photon beams, the energy spectrum (2) is assumed. Results are shown for 1, 2, 5 and 10 fb^{-1} of integrated luminosities.